References

1. Semezhev N., Multiport Modulator/ N. Semezhev, J. Östh, A.A. Sytnik // Problems of control, information processing and transmission (CIPT-2017) Proceed. of the Internat. Scientific Conf., pp. 581-584, 2017

2. Luo, B. Performance analysis of serial and parallel six-port modulators / B. Luo, M.Y.-W. Chia // IEEE Transactions on Microwave Theory and Techniques, vol. 56, no. 9, pp. 2062–2068, 2008.

3. Serban, A. Six-port transceiver for 6-9 ghz ultrawideband systems/ A. Serban, J. Osth, Owais, M. Karlsson, S. Gong, J. Haartsen, P. Karlsson// Microwave and Optical Technology Letters, vol. 52, no. 3, pp. 740–746, 2010. [Online]. Available: http://dx.doi.org/10.1002/mop.25021

4. Loke, A. Direct conversion radio for digital mobile phones-design issues, status, and trends/ A. Loke, F. Ali// IEEE Transactions on Microwave Theory and Techniques, vol. 50, no. 11, pp. 2422–2435, 2002.

5. Brenna, G. A 2-ghz carrier leakage calibrated direct-conversion wcdma transmitter in 0.13-um cmos/ G. Brenna, D. Tschopp, J. Rogin, I. Kouchev, Q. Huang// IEEE Journal of Solid-State Circuits, vol. 39, no. 8, pp. 1253–1262, 2004

6. Ciccognani, W. A novel broadband mmic vector modulator for v-band applications / W. Ciccognani, M. Ferrari, F. Giannini, E. Limiti // Int. J. RF Microw. Comput.-Aided Eng., vol. 20, pp. 103–113, January 2010. [Online]. Available: http://portal.acm.org/citation.cfm?id=1687193.

7. Semezhev N., Diode power detectors in software defined radio applications / N. Semezhev, D.A. Bulykin // Advanced Information Technologies and Scientific Computing (PIT 2016): Proceed. of the Internat. Scientific Conf. / Ed. S.A. Prokhorov, Russia, Samara: Samara Scientific Center of RAS, 2016.– P. 23-29.

8. Ashtiani, A. E. Direct multilevel carrier modulation using millimeter-wave balanced vector modulators/ A. E. Ashtiani, S.-I. Nam, A. d’Espona, S. Lucyszyn, I. D. Robertson// IEEE Transactions on Microwave Theory and Techniques, vol. 46, no. 12, pp. 2611–2619, 1998.

9. Osth, J. Direct carrier six-port modulator using a technique to suppress carrier leakage /J. Osth, O.M. Karlsson, A. Serban, et.al. // IEEE Transactions on Microwave Theory and Techniques, vol. 59, no. 3, pp. 741–747, 2011.

N. Semezhev

IMPACT OF PHASE SHIFTING NETWORK ON CARRIER LEAKAGE SUPPRESSION AND ERROR VECTOR MAGNITUDE

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Introduction

One way to ensure low carrier leakage is to have a 90° phase shift between ports in each port pair (P3, P4) and (P5, P6), respectively. In general the phase shift and amplitude scaling between the ports in a port pair will deviate from their ideal values when the actual frequency deviates from the center (designed) frequency f_0. Operating at a frequency where the amplitude and/or phase shift is not ideal will degrade the carrier leakage suppression and error vector magnitude (EVM) performance. Hence a model to predict the performance as a function of the S-parameters of the phase shifting network is derived. Using the derived model, a wideband phase shifting network is proposed and optimized. A six-port modulator using the wideband phase shifting network is shown in Fig. 1.

Theory

The reflection coefficient Γ_x looking out of port Px of the six-port and towards the phase shifting network (the two port network) is given by

$$\Gamma_x = S_{11} + \frac{S_{12}S_{21}\Gamma_{L,x}}{1 - S_{22}\Gamma_{L,x}} \tag{1}$$

where $\Gamma_{L,x}$ is the reflection coefficient looking into the impedance load Z_x and modeled according to $\Gamma(V) = \Gamma(V_{CM} + \Delta v) = \Gamma_{CM} + \Delta\Gamma \approx \Gamma_{CM} + \delta\Delta v$ [1], i.e.,

$$\Gamma_{L,x} = \Gamma_{CM} + \Delta\Gamma_x \tag{2}$$

The S-parameters for the phase shifting network are assumed to be given by

$$S = \begin{bmatrix} 0 & Ae^{-j\varphi} \\ Ae^{-j\varphi} & 0 \end{bmatrix} \tag{3}$$

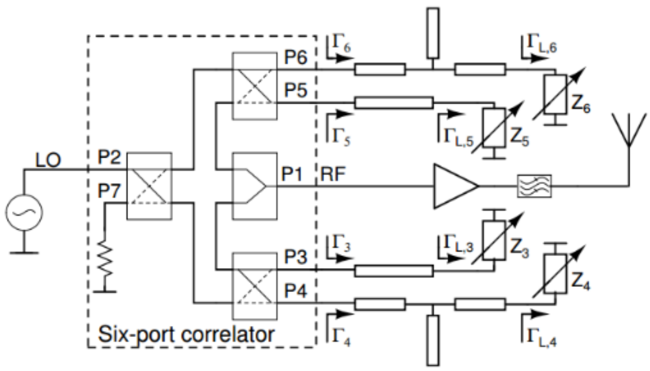

Fig. 1. Schematic of the six-port modulator using a broadband phase shifting network to suppress carrier leakage [2]

where $S_{12} = S_{21} = Ae^{-j\varphi}$ and A the amplitude scale factor and φ the phase shift. Calculating for I-channel $\Gamma_I = \Gamma_3+\Gamma_4$ and by using $\Delta\Gamma_3 = -\Delta\Gamma_4 = \Delta\Gamma$ it follows from (1) - (3)

$$\begin{aligned}\Gamma_I &= \Gamma_3 + \Gamma_4 = \Gamma_{L,3} + A^2e^{-j2\varphi}\Gamma_{L,4} = \\ &= \underbrace{\Gamma_{CM}\left(1 + A^2e^{-j2\varphi}\right)}_{Carrier\,leakage} + \underbrace{\Delta\Gamma(1 - A^2e^{-j2\varphi})}_{ModulatedRF}\end{aligned} \tag{4}$$

where $\varphi = 0$ and $A = 1$ were used for the phase shifting network responsible for Γ_3. As expected from previous analysis, when $A = 1$ and $\varphi = 90^\circ$ there is no carrier leakage and $\Gamma_I = 2\Delta\Gamma$. If $A \neq 1$ and/or $\varphi \neq 90^\circ$ the Γ_I vector is distorted resulting in both carrier leakage and EVM degradation. Owing to circuit symmetry the same analysis holds for the Q-channel as well.

Carrier Leakage Dependence on Amplitude and Phase Mismatch

To find the carrier leakage (4) is used with $\Delta\Gamma = 0$. For matched ports, the transmitted output power $P_{TX} = |b_1|^2/2$ is related to the LO power $P_{LO} = |a_2|^2/2$ by $b_1 = -\frac{a_2}{4}[(\Gamma_3 + \Gamma_4) + j(\Gamma_5 + \Gamma_6)]$:

$$P_{TX} = \frac{P_{LO}}{16}(|\Gamma_I|^2 + |\Gamma_Q|^2) \tag{5}$$

The same impedance loads Z_x are assumed to be used on ports P3 - P6, therefore $\Gamma_Q = \Gamma_I$. Using (4) in (5) it follows that the leakage power ratio $R_{leakage}$ is

$$R_{leakage} = \left.\frac{P_{TX}}{P_{LO}}\right|_{\Delta\Gamma=0} = \frac{|\Gamma_{CM}|^2}{8} E_f \,, \tag{6}$$

where

$$E_f = 1 + A^4 + 2A^2\cos(2\varphi)$$

is the error function and is dependent on the actual amplitude A and phase φ of the phase shifting network. In the ideal case $A = 1$, $\varphi = 90^\circ$ and $E_f = 0$, so there is no carrier leakage according to (6). Hence by knowing how A and φ vary with frequency, i.e., if the S-parameters of the phase shifting network are known, the carrier leakage suppression can be predicted.

EVM Dependence on Amplitude and Phase Mismatch

The EVM is given by [3]

$$EVM = \sqrt{\frac{\frac{1}{N}\sum|\Gamma_I - \Gamma_{I,ref}|^2 + |\Gamma_Q - \Gamma_{Q,ref}|^2}{\frac{1}{N}\sum|\Gamma_{I,ref}|^2 + |\Gamma_{Q,ref}|^2}} \tag{7}$$

Owing to symmetry both the I and Q channels will be affected in the same way so only the I channel is calculated. The reference (ideal) $\Gamma_{I,ref}$ magnitude square is found by using $A = 1$ and $\varphi = 90^\circ$ in (4)

$$|\Gamma_{I,ref}|^2 = 4|\Delta\Gamma_I|^2 \tag{8}$$

the actual error vector $\Gamma_{I,error}$ is

$$|\Gamma_{I,error}|^2 = |\Gamma_I - \Gamma_{I,ref}|^2 = |\Gamma_{CM} - \Delta\Gamma_I|^2 E_f \tag{9}$$

using (8) and (9) in (7) the EVM is then found to be

$$EVM = \sqrt{E_f}\sqrt{\frac{\sum|\Gamma_{CM} - \Delta\Gamma_I|^2 + |\Gamma_{CM} - \Delta\Gamma_Q|^2}{\sum\left(4|\Delta\Gamma_I|^2 + 4|\Delta\Gamma_Q|^2\right)}}$$

The EVM is therefore proportional to the square root of the error function E_f. For the special case $\Gamma_{CM} = 0$ there is no carrier leakage according to (6) and the EVM is only dependent on E_f as $EVM_{|\Gamma_{CM}=0} = \sqrt{E_f}/2$. The link between EVM and E_f and therefore to the S-parameters of the phase shifting network can be utilized to design a phase shifting network with good performance.

Broadband Phase Shifting Network Using Loaded Transmission Lines

A phase shifting network based on adding a TL of length $\lambda/4$ at specific ports, e.g., at port P4 and P6, works well for narrowband applications. However, for more wideband applications, a broadband phase shifting network should be used. Between many possible solutions our approach is based on a loaded transmission line [4]. A six-port modulator using a phase shifting network based on the loaded transmission line is shown in Fig. 1. Referring to Fig. 2, the references branch is a TL with an electrical length $\varphi_r = 270^\circ$. In the other branch a TL of electrical length $2\varphi_m = 180^\circ$ is loaded with an open circuit (O.C) stub at the center with length $\varphi_s = 180^\circ$. All electrical lengths are defined at the center frequency f_0. Compared to a single TL, the loaded TL helps to keep the phase difference close to 90° over a wider bandwidth. Amplitude and phase variations over frequency depend on the impedances Z_m and Z_s. Hence the phase shifting network can be optimized for carrier leakage suppression and the minimum EVM degradation, if the optimization goal is to minimize E_f over the frequency range of interest.

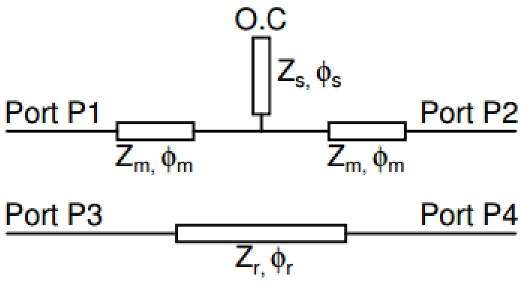

Fig. 2: Broadband phase shifter using a loaded transmission line [2].

Results

Since the use of $\lambda/4$ TL is a narrow-band phase shifting network, the performance will degrade outside of the center frequency. The simulated performance of E_f, and therefore the carrier leakage suppression according to (6), for a phase shifting network based on a TL and for the broadband phase shifting network is compared in Fig. 3.

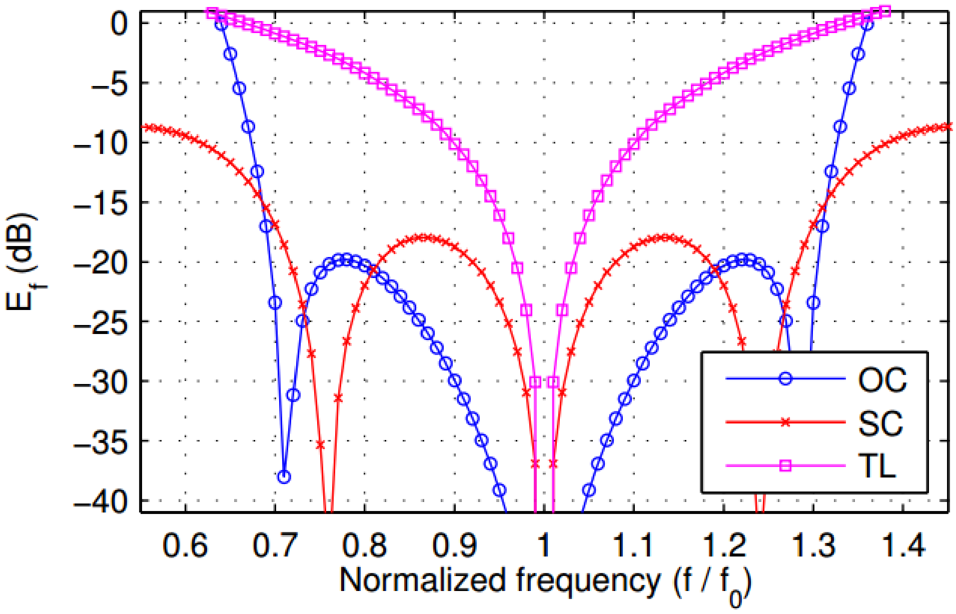

Fig. 3. Simulated E_f for a transmission line phase shifting network (TL) and for the optimized broadband phase shifting network terminated with an open circuit (OC) and short circuit (SC) [2]

In the simulation an ideal sixport correlator is used. Hence by implementing the broadband phase shifting network instead of the $\lambda/4$ TL the carrier leakage can be suppressed over a much wider bandwidth. For an EVM of less than 10% requires $E_f \leq -14$ dB. An EVM of less than 10% is achived with the broadband phase shifting network over a relative bandwidth of about 60%, to compare with the relative bandwidth of about 12% for the $\lambda/4$ TL phase shifting network.

Conclusion

The performance of the carrier leakage suppression and the modulation performance in terms of EVM were further investigated as a function of the phase shifting network. Both carrier leakage suppression and the EVM performance can be described by the same error function. The error function is directly related to the amplitude and phase behavior of the phase shifting network, i.e., it is related to the S-parameters of the phase shifting network. For wideband performance, a loaded TL was proposed as one possible solution to implement the phase shifting network. It was designed and optimized with help of the derived error function.

References

1. Semezhev N., Multiport Modulator/ N. Semezhev, J. Östh, A.A. Sytnik // Problems of control, information processing and transmission (CIPT-2017) Proceed. of the Internat. Scientific Conf., pp. 581-584, 2017

2. Osth, J. Carrier leakage suppression and evm dependence on phase shifting network in six-port modulator/J. Osth, O.M. Karlsson, A. Serban, S. Gong // Proc. Int. Conf. Microwave and Millimeter Wave Technology (ICMMT), vol 4., 2012.

3. Gu, Q. RF System Design of Transceivers for Wireless Communications./ Q. Gu // Secaucus, NJ, USA: Springer-Verlag New York, Inc., 2006.

4. Zheng, S. Y. Broadband phase shifter using loaded transmission line/ S. Y. Zheng, W. S. Chan, K. F. Man // IEEE Microwave and Wireless Components Letters, vol. 20, no. 9, pp. 498–500, 2010.

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NO-FIT POLYHEDRON FOR IRREGULAR PACKING
OF NON-CONVEX OBJECTS

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1. Introduction

The emergence of additive technologies and rapid prototyping techniques revolutionized the high-tech industries, for instance aviation and aerospace industry, nuclear industry, medical and instrumentation. They are characterized as small-scale or piece production. Using new methods for the synthesis of forms and synthesis models by layering synthesis technology allowed to drastically reduce the time to create new products. Since a number of independent parts can be manufactured simultaneously, the implementation of such technologies leads to the necessity of solving the problem